Engineering Structures xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Seismic evaluation of Romanian traditional buildings with timber frame and mud masonry infills by in-plane static cyclic tests

Andreea Dutu[a,*], Mihai Niste[a], Iulian Spatarelu[a], Daniel Ioan Dima[a], Shoichi Kishiki[b]

[a] Technical University of Civil Engineering Bucharest, Romania
[b] Tokyo Institute of Technology, Yokohama, Japan

ARTICLE INFO

Keywords:
Traditional
Timber
Mud masonry
Experiments
Seismic evaluation

ABSTRACT

The Romanian territory has an important seismic potential in Europe, with the Vrancea source. The most destructive seismic events that occurred in Romania in the 20th century (November 10, 1940 and March 4, 1977) have revealed a high level of seismic vulnerability of the built environment. An important part of this built environment is represented by historical buildings, including the traditional ones (timber frame and infills from various materials as brick, stone, adobe, etc.). The investigations after seismic events from November 10, 1940 and March 4, 1977, revealed that the traditional buildings did not suffer any or important damages, thus showed their particular seismic behavior.

Both the experience after similar seismic events from other countries as Turkey, Haiti, China, Myanmar, etc. and research studies from countries like Portugal, France and Japan, revealed an unexpected good behavior of such of buildings. Therefore, in this paper the results of the static cyclic tests on walls are presented. The test specimens were built according to the findings of the field investigations done on traditional buildings from Romania which are briefly presented hereby. The typology on which this paper focuses is the one found as predominant in the investigated areas (around the Vrancea seismic source).

1. Introduction

The present paper has as goal the seismic evaluation of traditional buildings with timber frame and mud masonry infill, which have proven over the time to be an earthquake resistant structure and with a remarkable architectural potential. Many countries in the world have structures with timber skeleton and masonry infill or other kind of infills, representing valuable heritage.

In some countries, timber framed walls were built most for aesthetical and architectural purposes (i.e. Germany, France, Czech Republic, etc.), although they may have structural role at least under gravitational loads. In others countries, they also have an earthquake resistance contribution (i.e. Portugal, Italy, Turkey, etc.) [1]. Timber framed masonry (TFM) system is also being presently used as reconstruction solution of areas that were destroyed by major earthquakes (i.e. Portugal, Pakistan) [1].

In most of the countries where these types of buildings are found, except Portugal and Italy, they were built without being based on any design regulation, but there are some situations (i.e. Turkey), where even if they date since 15th century, it was observed how people adapted their houses to local seismicity and made the structure as earthquake resistant as possible. Their behavior under earthquakes could be seen after some strong events as Kocaeli 1999, Kashmir 2005 or Haiti 2010. In the Izmir seismic event it was noticed that even if their damage state was advanced, at least they still stood up, while other types of structures fell [2]. In some situations, buildings with timbered masonry showed few damages (minor cracks, plaster falls, etc.), while poorly executed reinforced concrete structures near them collapsed or showed extensive damage [3].

Experimental studies were previously carried out for different configurations [4–9]. The common result was confirmation of the excellent behavior of in plane masonry infilled timber frames under cyclic loading, which is characterized by a significant ductility. Detailed and simplified numerical models were also developed for timber frames with masonry infills [10–12].

In Romania, in the last years, the studies on earthquakes produced an increase in the awareness of the population and authorities. For example, the most seismic exposed cities from Romania are Bucharest and Iasi. In Bucharest, according to seismic code P100-1/1992 the a_g (maxim expected seismic ground acceleration) was 0.20 g and today,

* Corresponding author.
E-mail addresses: andreea.dutu@utcb.ro (A. Dutu), mihai.niste@utcb.ro (M. Niste), iulianspa@utcb.ro (I. Spatarelu), officedanieldima2012@yahoo.ro (D.I. Dima), kishiki.s.aa@m.titech.ac.jp (S. Kishiki).

https://doi.org/10.1016/j.engstruct.2018.02.062
Received 17 March 2017; Received in revised form 6 November 2017; Accepted 19 February 2018

according to code P100-1/2013 a_g is 0.30 g (50% increasing) and for Iasi city, it was also 0.20 g and increased to 0.25 g (25% increase).

After the two major earthquakes that occurred in Romania on November 10th, 1940 and March 4th, 1977, there is not much information about traditional buildings with timber frame and masonry infill or other infills which suffered complete collapse or major damages. Thus, people generally assume that traditional residential houses behaved well during seismic events.

According to the last census in 2011, 43% of the built environment (residential) in Romania are the traditional houses divided in timber structures (10%) and timber frames with infills together with adobe houses (33%) [20]. Most of these date from 1946 to 1960 period [21]. Recently, due to the reinforced concrete structures' popularity, the traditional construction methods were not used, and it seems they are becoming lost, as very few people still know the secrets related to how to correctly build a traditional house.

Nowadays, the tendency is to promote such traditional houses with infilled timber frame structure, due to their heritage value, being Romania's cultural identity in terms of rural residential housing. They are also easy to build, relatively cheap, ecologic, aesthetic and, the most important, as the recent studies have shown, they have a satisfactory seismic resistance and especially a high ductility, aspect also revealed by the past seismic events in other countries. In this moment, in Romania, for this type of structures there is no specific design method specified in the national Code P100-1/2013, and also no evaluation procedures for this existent type of building.

In Romania, there are places where the buildings with infilled timber frame structure are inspired by the German "Fachwerk" traditional buildings, as there are in Sinaia city and its surroundings (Fig. 1). However, this area is not considered pure traditional Romanian, so the studies did not go further on this direction.

Also, there are other places, in rural areas, where people build this type of structure due to the local tradition of the area, such as Buzau or Vrancea county area [personal communication] (see Fig. 2). It seems that traditional way of building is actually the result of the adaptation of tens or hundreds of years to local seismic culture [13], but also to raw materials availability.

Thus, this fact is also confirmed by the actual use of this structure type by regular people that, despite of their lack of engineering knowledge, adopted it because they saw that neighbors having same type of house didn't have problems in the past earthquakes (from personal communication with villagers during field investigation). This situation is found at least in Romania, where engineering studies regarding behavior of infilled timber frames only recently started and so far no design procedure was issued with this subject.

Due to this reason, in Technical University of Civil Engineering Bucharest, a research project was started – TFMRO project – to evaluate the seismic resistance of traditional residential buildings, in order to validate a proposed evaluation method [14]. In this paper, a part of the project is presented, consisting of a brief summary of the field investigation with a focus on the timber frames with mud brick infills, their construction characteristics and static cyclic tests on two walls, with same characteristics and only difference the position of the diagonal braces.

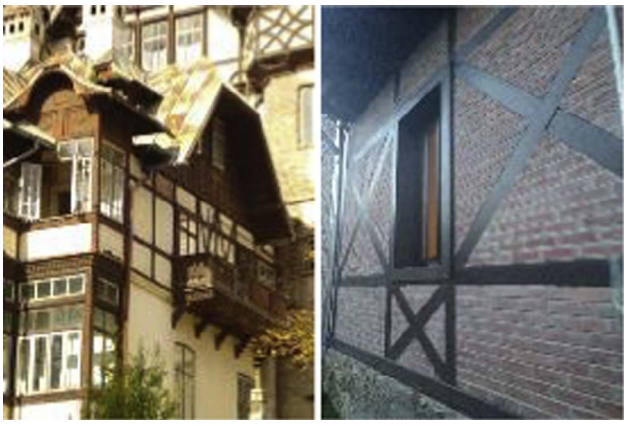

Fig. 1. Old (left) and new (right)"Fachwerk" architecture in Sinaia city, Romania [1].

Fig. 2. Traditional infilled timber frame house from Buzau county [4].

2. Field investigations

In order to study the seismic behavior of the traditional houses in Romania, for the field investigation only some regions were selected, located near the Vrancea source and nearby mountain and hill regions in Buzău county, Vrancea county [15], Dâmbovița county, Prahova county, Argeș county and Vâlcea county (Fig. 3).

Within the field investigation, among 129 traditional houses, five types of houses were observed (having resemblance with traditional houses) [16], with corresponding approximate percentage such as:

- with timber skeleton and brick masonry infill structure (Type 1 – "paianta", Fig. 4) – 70%;
- with timber skeleton and strips applied at 45° and clay plaster (Type 2, Fig. 5) – 15%;
- with timber skeleton and wattle and daub (Type 3, Fig. 6) – 15%;
- with timber skeleton and horizontal strips, infilled with earth and straw (Type 4 – "grădele", Fig. 7) – just 3 cases (so they were not taken into account in the statistics).
- with timber skeleton and AAC (autoclaved aerated concrete) masonry infill (Type 5, Fig. 8) – just 2 cases (so they were not taken into account in the statistics).

About the period of construction, approximate information is that 73% of them are between 60 and 90 years old; 14% of them are older than 100 years and 13% are younger than 60 years old. The statistics are approximate, due to the fact that many of them were covered with finishing, and could not be identified exactly, except by asking the owners who were not able in most of the cases to identify structural system correctly. The field investigation had as a reference the forms provided in [17,18].

2.1. Timber frames with mud brick infill structures

Type 1 – paianta – structure was found as predominant in the investigated areas, so this paper will focus on this typology. Further the construction details will be described, as far as they could be observed from the abandoned houses that were found, from which usually the finishing had fallen off due to poor maintenance. Some of the houses that were investigated were abandoned, while others were well maintained and owners didn't complain about special problems with them. Most often problem observed was the biotic decay and also the poor